Memorandum of Understanding Between SNOLAB and COUPP To Operate the COUPP 4-kg Bubble Chamber at SNOLAB

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Overview

The COUPP 2-liter bubble chamber is an upgrade of the original 1-liter COUPP bubble chamber which was designed and constructed at the University of Chicago in 2004 and was in operation in the MINOS near detector hall at Fermilab from 2005 through 2008. The early work with the 1-liter chamber demonstrated the technical feasibility of a large, clean, continuously stable bubble chamber as a dark matter detector and the exceptional $\sim 10^{10}$ rejection of gamma and beta recoil backgrounds, and produced new limits[1] on spin-dependent WIMP-nucleus interactions.

While notably successful in gamma and beta recoil discrimination, the maximum size of a dark matter bubble chamber was technically limited by the rate of bubble nucleation on the vessel walls, and the physics reach of the bubble chamber technique has been limited by background events due to alpha decays of unstable nuclei within the bubble chamber fluid. The COUPP 2–liter bubble chamber upgrade was initiated with three specific goals:

1) *Test the use of a synthetic silica inner vessel* to eliminate bubble nucleation on the vessel walls. Our working theory was that this class of events was due to alpha particle emissions from the vessel walls arising from the intrinsic Uranium and Thorium contamination of natural quartz.
2) *Demonstrate Improved fluid handling* procedures to minimize the injection of radon into the vessel during filling.
3) *Evaluate the acoustic alpha recoil discrimination* reported[2] by the PICASSO collaboration.

The COUPP 2-liter bubble chamber was installed in the MINOS near detector hall at Fermilab in August 2009 and ran through December 2009. It was successful in each of its stated goals. The synthetic silica vessel reduced the wall nucleation rate to a level sufficiently low for the largest chambers currently under consideration. By better choices of plumbing materials, we reduced the intrinsic alpha emitter contamination of the bubble chamber fluid to ~1 event/kg/day. Most important, the test resulted in a spectacular confirmation[3] of acoustic alpha discrimination, and in new world best limits for spin-dependent WIMP interactions[4]. Because the physics reach of the COUPP-2 liter bubble chamber was limited by the cosmic ray backgrounds at the 300-foot depth of the Fermilab MINOS site, the experiment is being moved from Fermilab to SNOLAB where it will operate at a depth of 6800 feet.

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[1] *Spin Dependent WIMP Limits from A Bubble Chamber. Science 319:933-936,2008*

[2] *Aubinet al., arXiv:0807.1536*

[3] "*COUPP progress report: results from the 4kg test chamber," C. Eric Dahl (Univ. of Chicago), Ninth UCLA Symposium on Sources and Detection of Dark Matter and Dark Energy in the Universe, Feb 24-25, 2010.*

[4] "New Dark Matter Limits from COUPP," Jeter Hall, Fermilab Joint Experimental Theoretical Seminar, March 19, 2010.

The Physical Elements of the Experiment, Resource Requirements

Exclusive of its shielding, the COUPP 2-liter bubble chamber experiment is a very small and easily portable device consisting of the bubble chamber itself, a small hydraulic controls unit, a small laboratory NESLAB heater/chiller unit, and a single data acquisition relay rack. The combined weight of all the elements (again exclusive of the veto/shielding) is less than 2000 lb and could be delivered in a single truckload. The COUPP 2-liter bubble chamber is illustrated in Figure **1**.

At the 6800-foot depth of the SNOLAB site, the experiment will not require active cosmic ray muon tagging. To shield the experiment against neutrons originating from the radioactivity of the surrounding rocks, the experiment will be surrounded by a thickness of 20 inches (50 cm) of polyethylene/water shielding. An elevation view of the chamber as it will sit in its shielding is provided as Figure **2**.

The footprint of the experiment is roughly 8‘ x 12’. This space is sufficient to contain the polyethylene/water shielding, the hydraulic cart, the NESLAB heater/chiller unit, the data acquisition rack, and a chair.

The resources required by the experiment are modest. The data acquisition rack requires a single 60 Hz, 110V, 20A circuit. The hydraulic cart is powered from the data acquisition rack. The NESLAB heater/chiller unit requires a separate 60 Hz, 110V, 20A circuit. To power auxiliary equipment used during installation and commissioning (vacuum pump, oil pump) a third separate outlet would be convenient. The hydraulic cart additionally requires a compressed air supply at >50 psig. The operation of the experiment consumes compressed air at a rate of less than 10 SCF per day.

Resource Requirements Summary:

Footprint:	8 x 12 feet ~100 square feet
Electrical:	(3) 60Hz, 110V, 20A circuits
Compressed Air:	>50 psig, <10 SCF/day
Radioactive Sources:	Encapsulated neutron and gamma sources.

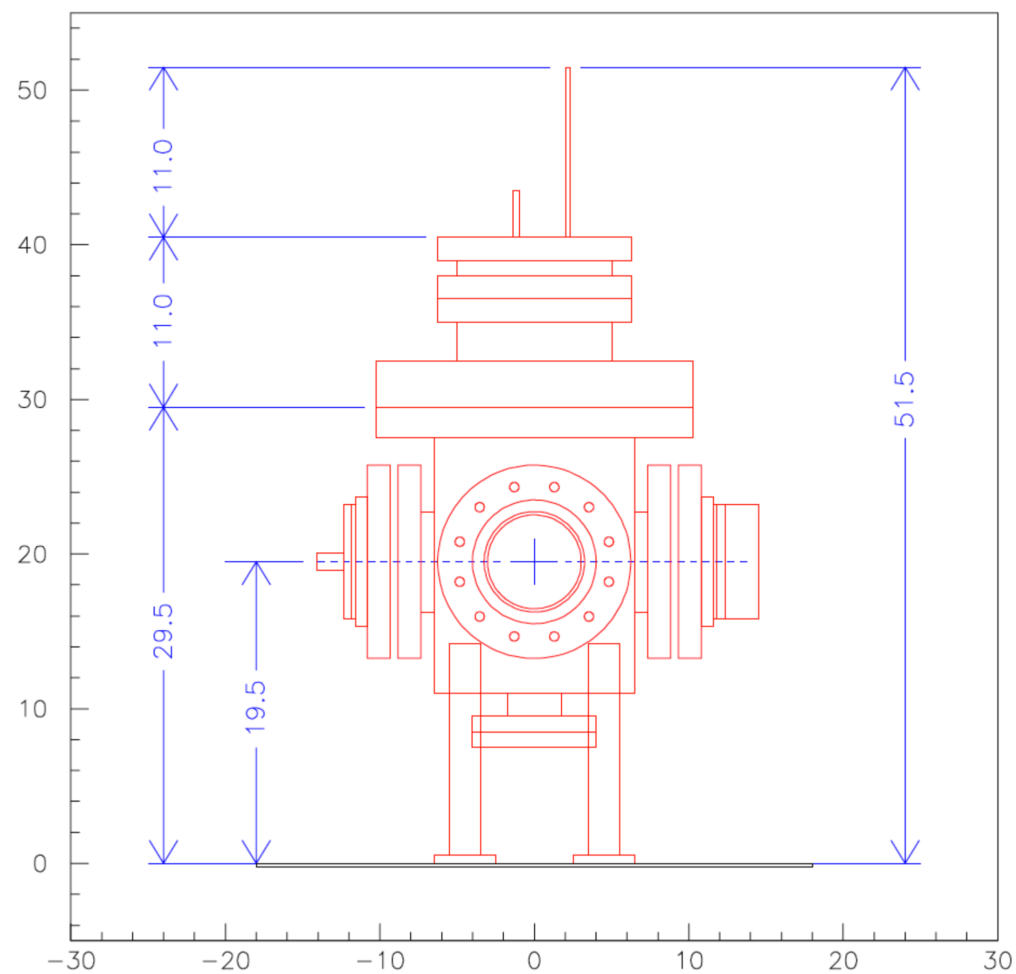

Figure 1: An Elevation View Cartoon of the COUPP 4-kg Bubble Chamber. Dimensions are in inches.

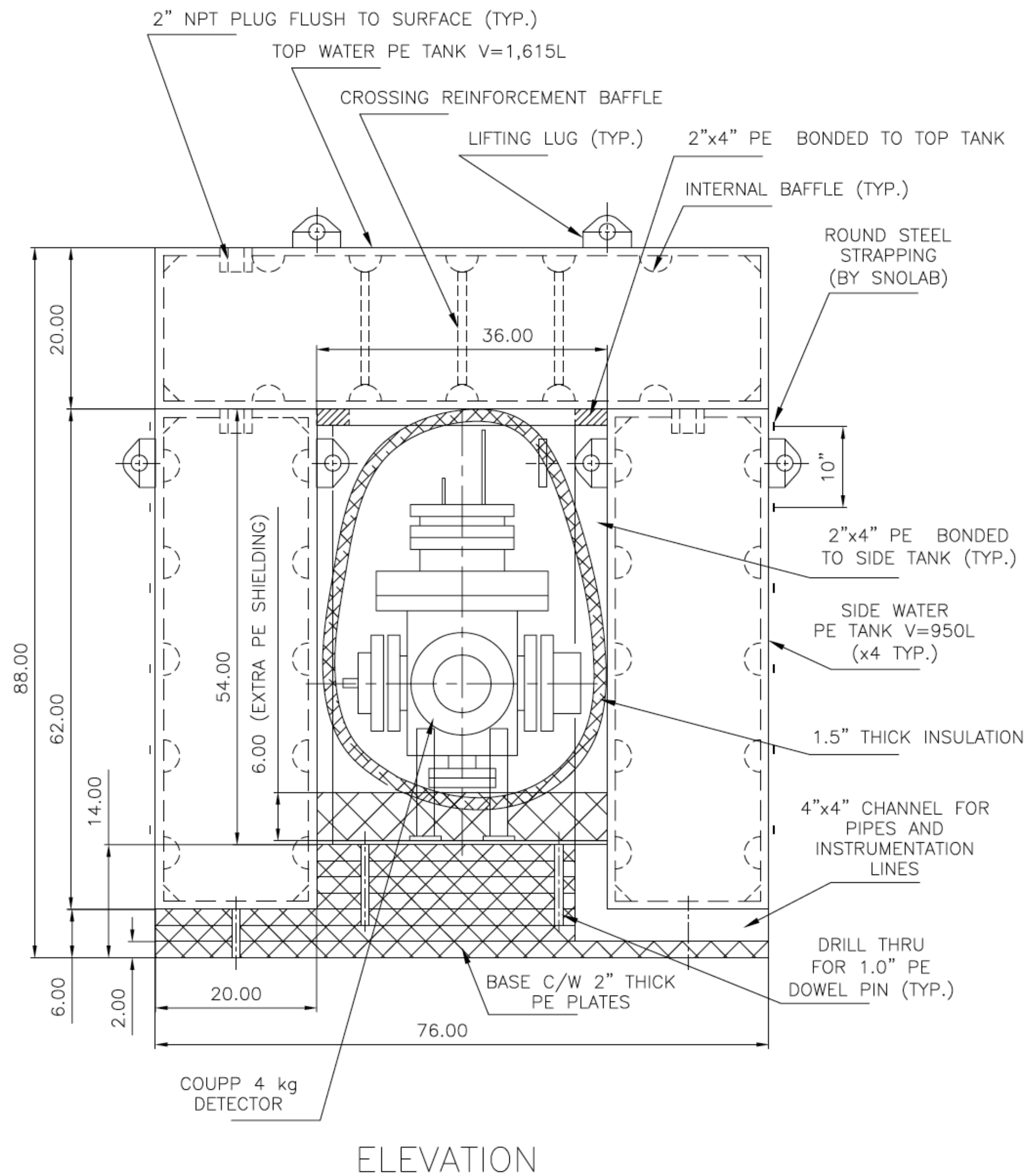

Figure 2: An Elevation Drawing showing the COUPP-4kg bubble chamber within its polyethylene/water shielding.

Figure 3: This photograph shows the COUPP 2-liter bubble chamber as it appeared in the Fermilab MINOS area installation. The Hydraulic Controls Cart is visible to the left and the NESLAB RTE-740 heater/chiller unit can be seen behind the chamber.

The Experimental Apparatus:

The elements of the COUPP 2-liter Bubble Chamber Experiment are listed below:

1) The Shielding consists of
    a. Base Slab of polyethylene 76" square, 6" high with additional raised polyethylene pedestal base 36" square, 8"high.
    b. Four Polyethylene/water side shield tanks 20"x56"x62" high.
    c. One Polyethylene/water top shield tank 76"x76"x20"high.

2) The Bubble Chamber
    a. One stainless steel pressure vessel, including
        i. Pressure Vessel Body
        ii. Pressure Vessel load distributing base plate
        iii. Top and bottom flanges
        iv. Top Flange Spacer
        v. Internal Heater/chiller coils
        vi. Four pressure rated 6" diameter viewports
        vii. Retro-reflective backdrop for photography
        viii. Two FireWire video cameras
        ix. LED array for photography illumination

    b. Inner vessel Assembly, including
        i. Quartz inner vessel
        ii. Pressure balancing bellows
        iii. Top flange assembly, plumbing and valves
        iv. Instrumentation (temperature and pressure transducers)
        v. Instrumentation (acoustic transducers)
        vi. Instrumentation wiring, feed-through, and breakout box.

3) The Data Acquisition and Controls Rack, including
    a. One National Instruments PXI Chassis with instrumentation modules
    b. One 1U rack-mount National Instruments SC-2345 Instrumentation Wiring Chassis.
    c. Two LINUX computers (one for data management and communications, one hot spare.)
    d. Auxiliary electronics modules
        i. 1U rack-mount Acoustic Transducer Bias Supply
        ii. 1U rack-mount LED driver module
        iii. A small commercial bias supply for a fast pressure transducer.

4) The Hydraulic Cart which includes
    a. Compressed air system
    b. Fast solenoid actuated pneumatic/hydraulic cylinder for fast compression
    c. Stepping motor driver slow hydraulic cylinder for pressure control
    d. Pressure and temperature instrumentation
    e. Commercial controls processor

f. Hydraulic plumbing connection to the bubble chamber pressure vessel.

5) The NESLAB heater/chiller unit
   a. A commercial NESLAB RTE-740 laboratory circulating heater/chiller
   b. Insulated circulation lines connecting the NESLAB bath to the heater/chiller coils in the bubble chamber pressure vessel

6) Cable Plant
   a. Roughly one dozen instrumentation, control, and network cables are required for the experiment

7) Auxiliary Equipment
   a. Vacuum Pump used in fluid handling and setup operations.
   b. Propylene glycol is (2) five-gallon plastic containers.
   c. Glycol handling hose and valve.
   d. CF_3I transport and handling equipment
      i. 4-liter Swagelok sample cylinder used for transport and transfer.
      ii. CF_3I transfer line
      iii. Refrigerant scale used to meter CF_3I transfer.
   e. Dummy hydraulic load for use in commissioning and testing the hydraulic cart with the DAQ.
   f. Dummy thermal bath load for use in commissioning and testing the NESLAB heater/chiller unit with the DAQ.
   g. Radioactive sources for use in chamber calibration and testing
      i. Sealed gamma sources 1-100 μCi
      ii. Sealed neutron sources ~few neutrons per second

The Deployment Plan:

Elements of the Experiment Grouped for Staging, Testing, and Deployment:
In broad strokes, elements of the experiment break into four groups for purposes of scheduling and logistical analysis, transport, staging, testing, and ultimately installation and commissioning in the SNOLAB underground facility.

1) Site Preparation and Infrastructure Elements, including
   a. Shielding Base Slab and Pedestal
   b. The Bubble Chamber Pressure Vessel
   c. The Pressure Vessel Base Plate
   d. Electrical Distribution
   e. Compressed Air
   f. Network Connection

2) Data Acquisition and Instrumentation Elements, including
    a. The National Instruments PXI and SC-2345 Chassis
    b. The Acoustic bias, LED driver, and Dytran bias units
    c. The Linux computers
    d. The Cameras and LEDs
    e. The instrumentation and network cables
    f. Computer peripherals, including
        i. Network switch
        ii. KVM switch
        iii. Monitors, keyboards, mice

3) Inner Vessel Assembly, including
    a. Quartz inner vessel
    b. Pressure balancing bellows
    c. Top flange assembly, plumbing and valves
    d. Instrumentation (temperature and pressure transducers)
    e. Instrumentation (acoustic transducers)
    f. Instrumentation wiring, feed-through, and breakout box.

4) Shielding Tanks
    a. Four Polyethylene/water side shield tanks 20"x56"x62" high.
    b. One Polyethylene/water top shield tank 76"x76"x20"high.

Four Sequences of Events:
Again, in broad stokes, the plan for getting the experiment ultimately assembled in the SNOLAB underground facility is as follows

1) Underground Site Preparation
    a. Agree upon a final location and footprint for the experiment
    b. Prepare and approve final drawings for the
        i. The experiment layout
        ii. Shielding elements
        iii. Electrical, compressed air, network, and fire protection distribution

    c. Procure shielding elements
        i. Base slab and pedestal, side and top tanks

    d. Ship Pressure Vessel and Pressure Vessel Base Plate to SNOLAB
    e. Clean and Deliver components to SNOLAB Underground area.
    f. Execute the Site Preparation Elements, including
        i. Install electrical, compressed air, fire protection, lighting.
        ii. Install and level shielding base slabs and pedestal
        iii. Install pressure vessel on its base plate on the shielding pedestal.

2) DAQ and instrumentation commissioning: [*note: the original FNAL COUPP 2L DAQ will be kept in tact at Lab F at Fermilab. The SNOLAB COUPP 2L DAQ will be assembled from new (and approximately identical) components. That will allow us to complete DAQ software development on the old system while commissioning the new system.*]
    a. Complete DAQ modifications and testing using the FNAL DAQ at Lab F.
    b. Receive new DAQ elements at the Lab 3 North clean room at Fermilab
    c. Perform First Level Commissioning activities, including
        i. Acceptance testing (where appropriate) of components
        ii. Software installation and configuration
        iii. Network interconnectivity tests.
        iv. Full system DAQ software tests

    d. Re-package DAQ equipment for shipment to SNOLAB
    e. Receive DAQ equipment at SNOLAB, clean and stage in an above ground laboratory space.
    f. Complete Level 2 Commissioning activities, including
        i. Populate Relay racks
        ii. Full system DAQ test
        iii. Network connectivity tests to Fermilab
        iv. Exercise of full data path including analysis and archive tools.

    g. Disassemble DAQ elements and prepare for and transport to the site of the underground installation.
    h. Set up the DAQ and instrumentation elements in final form in the underground site. This includes
        i. Place and set the hydraulic cart (it has screw jack leveling feet)
        ii. Complete the plumbing connection of the hydraulic cart to the pressure vessel
        iii. Setup the NESLAB unit and complete its insulated plumbing connections to the pressure vessel
        iv. Place the relay racks
        v. Cable the experiment, including
            1. Instrumentation cabling
            2. Control cabling
            3. Network cabling.

        vi. Fill the Pressure Vessel and hydraulic cart with propylene glycol and de-gas.

    i. Insulate the pressure vessel
    j. Complete Level 3 Commissioning Activities, including:
        i. Exercise the full DAQ and Controls system
        ii. Test Hydraulic Cart function
            1. Expansion/compression
            2. Pressure control

            3. Alarms and Limits

   iii. Test NESLAB temperature Regulation
   iv. Test Auto-Run DAQ capabilities
   v. Test remote operations functionality,
   vi. Test data path connectivity through to analysis and archiving at Fermilab

3) Inner Vessel Assembly
   a. Disassemble the original inner vessel assembly
   b. Bag and tag parts for transport to AD A0 cleaning facility
   c. Complete the cleaning and parts prep. This includes
      i. Inner vessel components (vessel, bellows, flanges, seals, etc…)
      ii. Water distillation components (still, lines)

   d. Assemble the inner vessel (vessel, bellows, and flanges, seals)
   e. Final rinse at A0
   f. Vacuum leak check.
   g. Package and transport to Lab 3 COUPP clean room.
   h. Set up and execute water distillation.
   i. Setup in the Lab 3 North clean room.
   j. Perform sensor installation and wiring, including
      i. Temperature transducers
      ii. Pressure transducers
      iii. Acoustic transducers.
   k. Test and calibrate where appropriate transducers.
   l. Package the inner vessel assembly for transport
   m. Transport the inner vessel assembly and CF3I handling equipment to SNOLAB.
   n. Receive, clean, and move underground.
   o. At this point, the inner vessel assembly is ready to mate with the already tested pressure vessel, hydraulic cart, NESLAB, and DAQ in the underground site.
   p. Install the inner vessel
   q. Evacuate and backfill the pressure vessel with glycol
   r. Cool the vessel and perform the CF_3I distillation/fill.
   s. Warm the chamber to its operating point and execute final commissioning tests, including
      i. Expansion, testing for stability, radon etc.
      ii. Use neutron source to confirm operations.

4) Shielding Tanks
   a. Agree upon Final Conceptual Design
   b. Obtain quotations based on the preliminary drawings.
   c. Finalize the design drawings

d. Procure the Tanks (Are the base slab elements available at an earlier time? The base is needed early. The tank installation is the last installation step.)
e. Receive the tanks, clean transport underground.
f. Test?
g. Install the shielding tanks, fill.

Resources and Responsibilities:
Again, in broad strokes, it is our understanding that the resources for the experiment will be provided as follows:

1) SNOLAB will provide
    a. Site preparation, including
        i. Electrical distribution
        ii. Compressed air
        iii. Fire protection
        iv. Lighting
    b. Shielding, including
        i. Shielding base slab and pedestal
        ii. Shielding tanks, side and top.
    c. Relay racks

2) University of Chicago Will Provide
    a. The Bubble Chamber Pressure Vessel
    b. The Data Acquisition System
        i. National Instruments PXI Chassis w/ embedded processor
        ii. Data Acquisition Modules
        iii. Software Licenses LabVIEW, LabVIEW VISION
        iv. Instrumentation Cabling
    c. Linux data handling computers (2)

3) Indiana University South Bend Will Provide
    a. Acoustic Transducers

4) Fermilab Will Provide:
    a. The Hydraulic Controls Cart
    b. The Inner Vessel Assembly
    c. The Acoustic Transducer Biasing Module
    d. The Photography elements, including
        i. FireWire Cameras
        ii. LED array
        iii. CAMERA/LED Interface Module
        iv. Retro-reflective backdrop
    e. Readout Components for the Acoustic Transducers, including
        i. Preamplifier boards

ii. Acoustic transducer bias box

Engineering and Technician Support From SNOLAB will include:

1) Engineering and Design Support for Site Preparation
    a. Appropriate drawings and specifications for
        i. Lighting and Electrical distribution
        ii. Compressed air Distribution
        iii. Fire Protection
        iv. Network Distribution
2) Engineering and Design Support for Shielding
3) Technician and other appropriate labor for installation of
    a. Site Infrastructure (lights, power, compressed air fire protection, network.)
    b. Shielding Base and Pedestal
    c. Shielding tanks

Engineering and Technician Support From Fermilab:

4) PPD Mechanical Department Support
    a. Process Flow Diagram
        i. Drafting for the Diagram
        ii. Mechanical Tech for component checking and tagging
        iii. Engineering Support for review and approval

    b. The Hydraulic Cart
        i. Mechanical Tech Support for revising the cart plumbing. This includes specification, procurement, and installation of new plumbing components.
        ii. Mechanical Tech Support for specifying and procuring plumbing components to connect the hydraulic cart to the experiment pressure vessel.

    c. The Inner Vessel Assembly
        i. Mechanical Tech Support for specification and procurement of miscellaneous expendables of the Inner Vessel Assembly. These include:
            1. Filters,
            2. Seals,
            3. Valve kits.

        ii. Mechanical Tech Support for disassembling the inner vessel components and for bagging and tagging them.
        iii. Mechanical Tech Support for overseeing the transport of inner vessel components to the Accelerator Division A0 Cleaning Facility.

iv. Mechanical Tech Support for Assembly of the inner vessel components. This includes
    1. Assembly and sealing of the top flange, the bellows, and the inner vessel
    2. Final rinse of the inner vessel assembly
    3. Vacuum Leak Checking
    4. Preparation of top flange components
        a. Valves assemblies
        b. Electrical feed-through
        c. Sensor attachment and wiring

v. Mechanical Tech Support for Water Fill/Distillation
    1. Mobilization of still components
    2. Overseeing the cleaning of still components at A0 (this task is likely integrated with the cleaning of the inner vessel components.)
    3. Assembly and preparation for the water distillation apparatus in the Lab 3 Clean Room.
    4. Execution of the water distillation process

vi. Preparation of the Inner Vessel Assembly for Transport.

5) PPD Technical Centers Department Support
    a. Design and Fabrication support for Auxiliary Shielding Pieces surrounding the chamber legs.
    b. Installation Support and Maintenance for KEPDirect PLC firmware and communications software.

6) PPD Electrical Engineering Department Support
    a. Engineering Design for Acoustic Transducer preamplifier boards
    b. Fabrication and assembly for preamplifier boards
    c. Engineering Design Support for Acoustic Transducer Bias Box modifications
    d. Engineering Design Support for Camera/LED interface box revisions.
    e. Engineering Design Support for Modifications to Hydraulic Cart Interface Box.